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AIR MINISTRY
METEOROLOGICAL RESEARCH COMMITTEE

A method of increasing the range of the Dobson-Brewer Aircraft Frost Point Hygrometer

by
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Summary

It has been thought that should there be a requirement to measure frost points below about -130°F the Dobson-Brewer hygrometer would fail as the frost deposit then becomes invisible. This paper describes a method which would increase the range of the hygrometer in jet aircraft by about 20°F by making the measurements in air which has been previously passed through the aircraft compressor.

Introduction

Up to the present the only accurate measurements of humidity at altitude in this country have been made by the Meteorological Research Flight. For the past few years regular flights have been made in Mosquito aircraft to its ceiling of about 40,000 feet for the main purpose of obtaining accurate humidity and temperature soundings at that height. These soundings up to 1951 are summarised and discussed in Reference 1. A study of these ascents will show that the lowest frost points usually measured were about -100°F with occasional readings down to about -120°F.

The method of obtaining these frost points depends upon the recognition of a frost deposit on a cooled metal thimble over which outside air is passing. The instrument is fully described in Reference 2. The operation of the hygrometer requires much experience as the frost deposit becomes more difficult to recognise the lower the frost point becomes. Indeed at a frost point of about -100°F the deposit is only confidently recognised by the most experienced operators. At temperatures below about -130°F any frost deposit may be glassy and so impossible to recognise. Therefore it is seen that the Dobson-Brewer hygrometer in its present form will fail if used to measure a frost point of below about -130°F.

It has been pointed out in a previous paper (Reference 3) that frost points of below -120°F will probably be found at the tropopause in tropical regions and occasionally at moderate altitudes in polar regions.

A study of the Mosquito soundings (Reference 1) will also show that the tendency of the frost points at about 40,000 feet over southern England, that is in the lower stratosphere, is to become lower. Should this tendency persist further into the stratosphere, then the Dobson-Brewer hygrometer may also fail at great heights over England.

The addition of a Canberra, with ceiling of over 50,000 feet, to the strength of the Meteorological Research Flight has made the problem more acute. With this situation in mind, experiments on the hygrometer installation in an Avro Ashton aircraft have been carried out, the details of which are given below.

/The

The method

Figure II is a simplified extended T Ø gram showing only the isobars, isotherms, the humidity mixing ratio and potential temperature isopleths. If air at 200 mb with a frost point of -92°F (say) is compressed to 1000 mb, the humidity mixing ratio would remain constant, although the temperature would change. The frost point of this air at 1000 mb is then readily seen to be -72°F. Thus the frost point would be made 20°F higher simply by compressing the air. The same procedure applied to air having a frost point of -150°F would similarly give a frost point of about -130°F if compressed to the same degree.

It therefore appears that, as suggested by Dr. A.W. Brewer, if the hygrometer can be supplied with compressed air, then its range will be increased at the lower end by an amount dependent on the degree of compression.

The compression of air to the extent required would be very inconvenient in piston engined aircraft. However an integral part of the jet engine is a fairly high ratio compressor. Indeed in the most modern jets the practice now is to use the engine compressors to supply the cabin pressurisation system instead of using separate "blowers".

It was therefore decided to attempt to supply the hygrometer in the Avro Ashton in a similar manner. The twelfth stage of the compressor on No. 3 engine was tapped and the pipe led through a needle valve to the intake pipe of a pressurised hygrometer. Pressure gauges were fitted in the intake and outlet pipes and gas tight cocks were also provided in these pipes. A diagram of the installation is shown in Figure I.

Operation of the modified hygrometer

By keeping the needle valve closed and opening the two cocks it was possible to measure the frost point of the outside air directly in the normal manner. But by opening the needle valve, to admit compressed air, and closing the cock in the normal intake pipe, the pressure inside the hygrometer could be controlled by partially closing the cock in the outlet pipe. To achieve such sensitive control of the internal hygrometer pressure, it was of course necessary to use an instrument with the liquid oxygen pump outside the pressure seal. The pressure gauges in the intake and outlet pipes enabled the internal hygrometer pressure to be measured. Three flights were made and are described below.

Flights I and II

These flights were made on 4th and 5th January, 1954 at 20,000 feet and 35,000 feet respectively, primarily for other than meteorological purposes. On both flights a series of frost points was measured with the internal hygrometer pressure at various values. Unfortunately on both flights a fault in the hygrometer shutter made it impossible to obtain frost points of the outside air in the orthodox manner.

The results are given below in Tables Ia and Ib. The evaluated true frost point, obtained by reference to an extended T Ø gram, is also given. On Figure II the frost points are plotted at their appropriate pressure. It is seen that in both cases the readings lie about a line of constant water content. Any deviation from this line is well within the limits of experimental error, especially when it is considered that atmospheric inhomogeneities could also cause some deviation.

/Table Ia

Table Ia (4/1/54)

Time	Height of a/c.	Air Temp.	Internal hygrometer pressure	Frost point at that pressure	Evaluated true frost point
G.M.T.	ICAN	°F	mb	°F	°F
1130	19700	-33	1296	-43	-57
1134	19700	-32	1013	-46	-57
1136	19700	-32	875	-48	-57
1139	19750	-32	758	-53	-59
1143	19700	-32	675	-54	-58
1146	19900	-32	944	-47	-57
1150	19800	-33	1234	-44	-57

Table Ib (5/1/54)

Time	Height of a/c.	Air Temp.	Internal hygrometer pressure	Frost point at that pressure	Evaluated true frost point
G.M.T.	ICAN	°F	mb	°F	°F
1214	34700	-82	585	-86	-97
1217	35000	-83	800	-83	-97
1221	34500	-83	723	-84	-97
1226	34700	-81	854	-79	-95
1230	34600	-81	944	-76	-93
1235	34600	-81	737	-82	-95

Flight III

This flight was carried out on 18th January, 1954 and was made mainly for the testing of the hygrometer system. Having shown on the previous two flights that changes in the internal pressure of the hygrometer caused the measured frost point to vary along a line of constant water content, the purpose of this flight was to compare the frost point measured normally with that found by using the hygrometer at a fairly high internal pressure.

Runs were made at 15, 20, 25, 30 and 35,000 feet during which measurements were taken using the orthodox method and others were taken with the internal hygrometer pressure at atmospheric. These results are presented in Table II and are given on a modified T Ø gram (Figure III). It is seen that the difference between the frost points arrived at by the orthodox and pressurised methods is again small enough to be accounted for by experimental error or atmospheric inhomogeneities.

Table II

Height	Air Temp.	Internal hygrometer pressure	Frost point at that pressure	Evaluated true frost point	True frost point as measured by orthodox method
ICAN	°F	mb	°F	°F	
15000	+5	1013	+3	-6	-5 and -7
20000	-11	1013	-18	-33	-33 and -32
25000	-31	1013	-45	-59	-63
30000	-55	1013	-59	-75	-77 and -78
35000	-76	1013	-65	-83	-85

/Conclusion

Conclusion

It is seen from Table II and Figure III that the increase of pressure from 238 mb (35,000 feet) to 1013 mb gives an improvement of 20°F in frost point. Therefore, should it be required, the range of the hygrometer can be increased by about 20°F or over depending upon the degree of compression.

Addendum

Whether it will be necessary to use this method to measure humidities above 40,000 feet over England is still not decided.

The first measurements of frost point to 50,000 feet made in the Canberra of the Meteorological Research Flight by the author are plotted on Figure IV. It is seen that on this occasion there was a "tropopause-like" change in the lapse rate of the frost point at about 44,000 feet. It is not proposed to discuss the significance of this result here, but future measurements will show whether this feature is a regular feature of the humidity of the stratosphere. However the hygrometer was nearing its limit on this flight and should lower frost points be encountered the method described above can readily be applied to the Canberra.

Acknowledgment

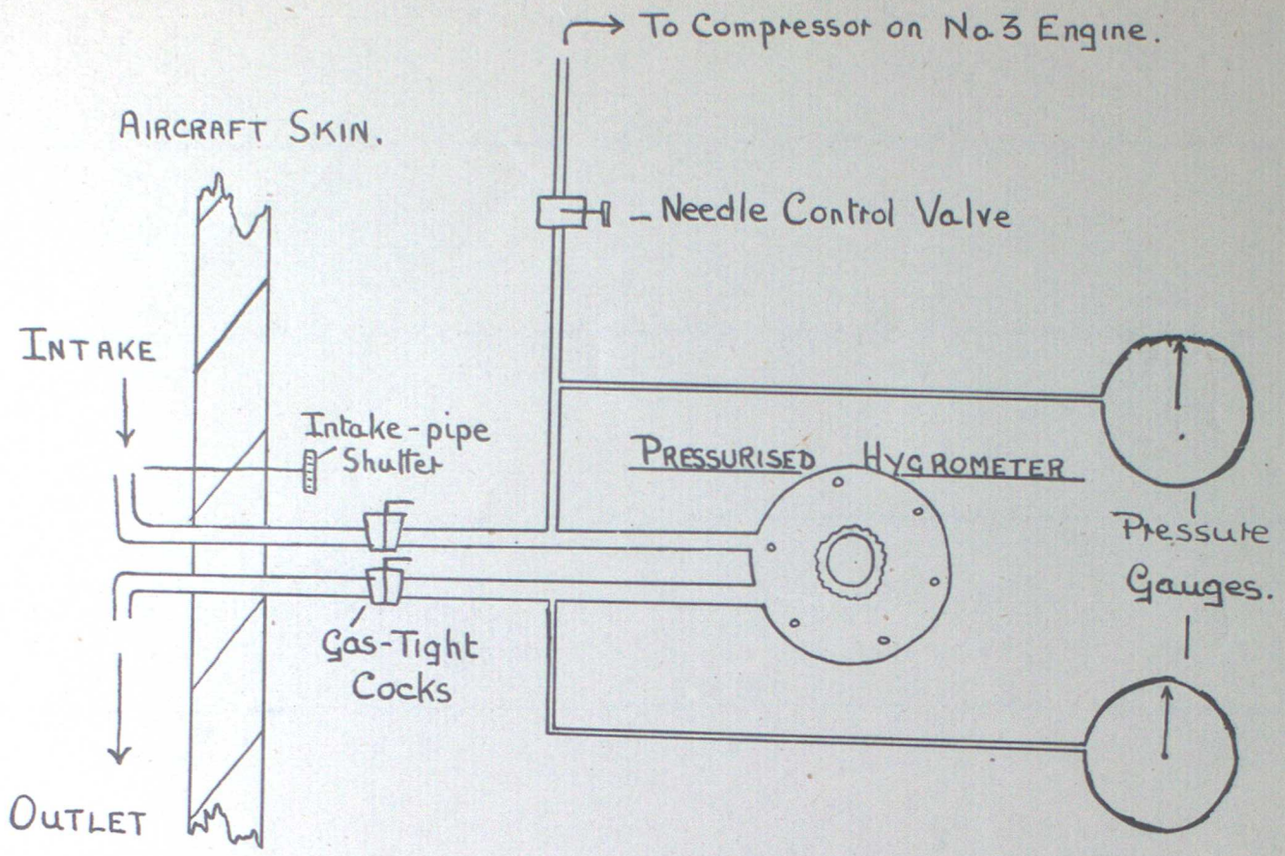
Acknowledgments are due to M.E. Department R.A.E. for their co-operation in allowing this work to be carried out on their aircraft, at a time when the Meteorological Research Flight did not have a jet aircraft.

References

(1) 1952 Bannon, J.K., Frith, R. and Shellard, H.C. Geophysical Memoirs No.88.

(2) 1948 Brewer, A.W., Cwilong, B.M. and Dobson, G.M.B. Proc. Phys. Soc., London, Vol. 60, (52 - 70).

(3) 1953 Goldsmith, P. M.R.P. 789.



Plan View of the Hygrometer Installation on the Avro-Ashton.

Figure I.

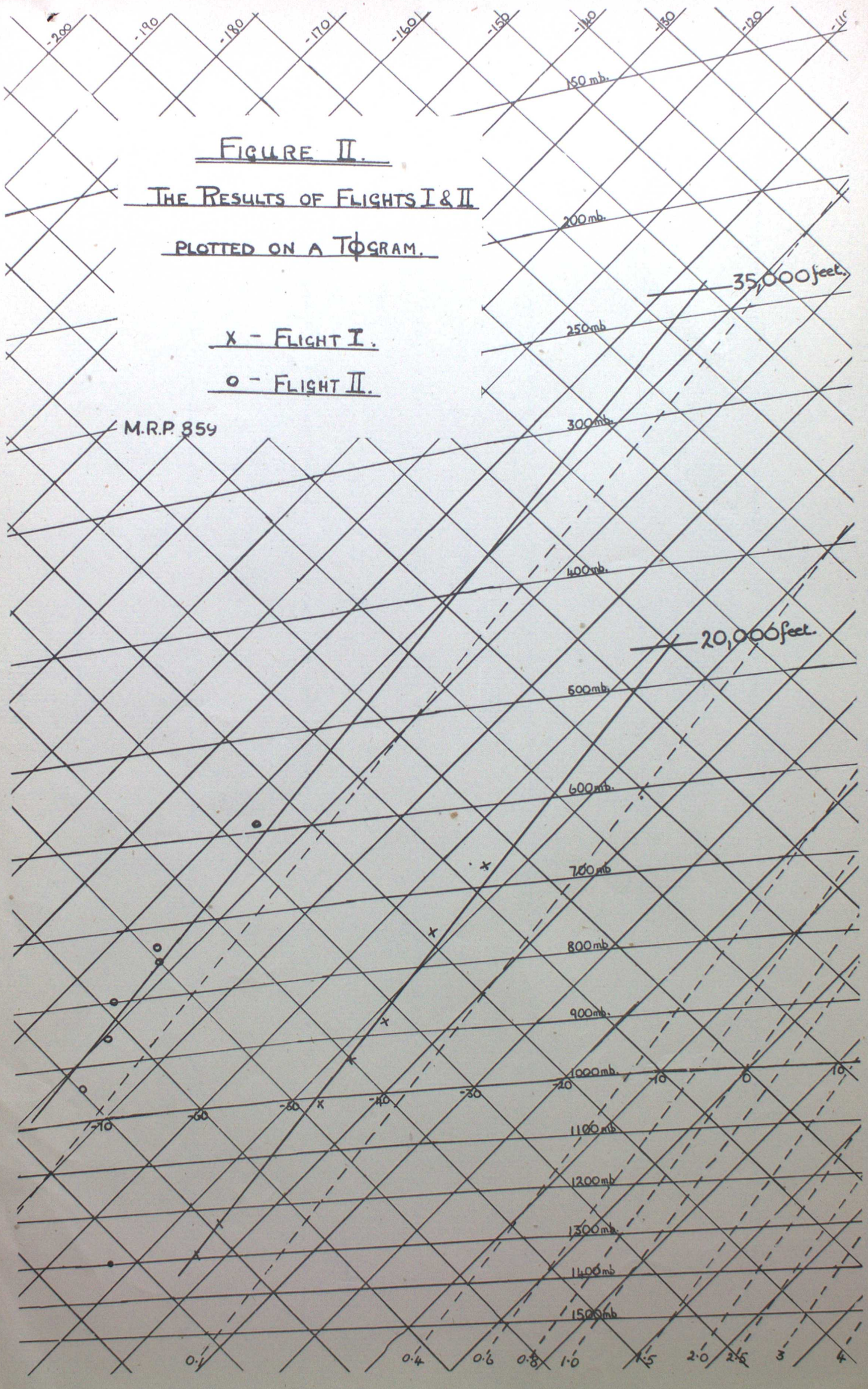


FIGURE II.

THE RESULTS OF FLIGHTS I & II PLOTTED ON A TΦGRAM.

X - FLIGHT I.

o - FLIGHT II.

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FIGURE III

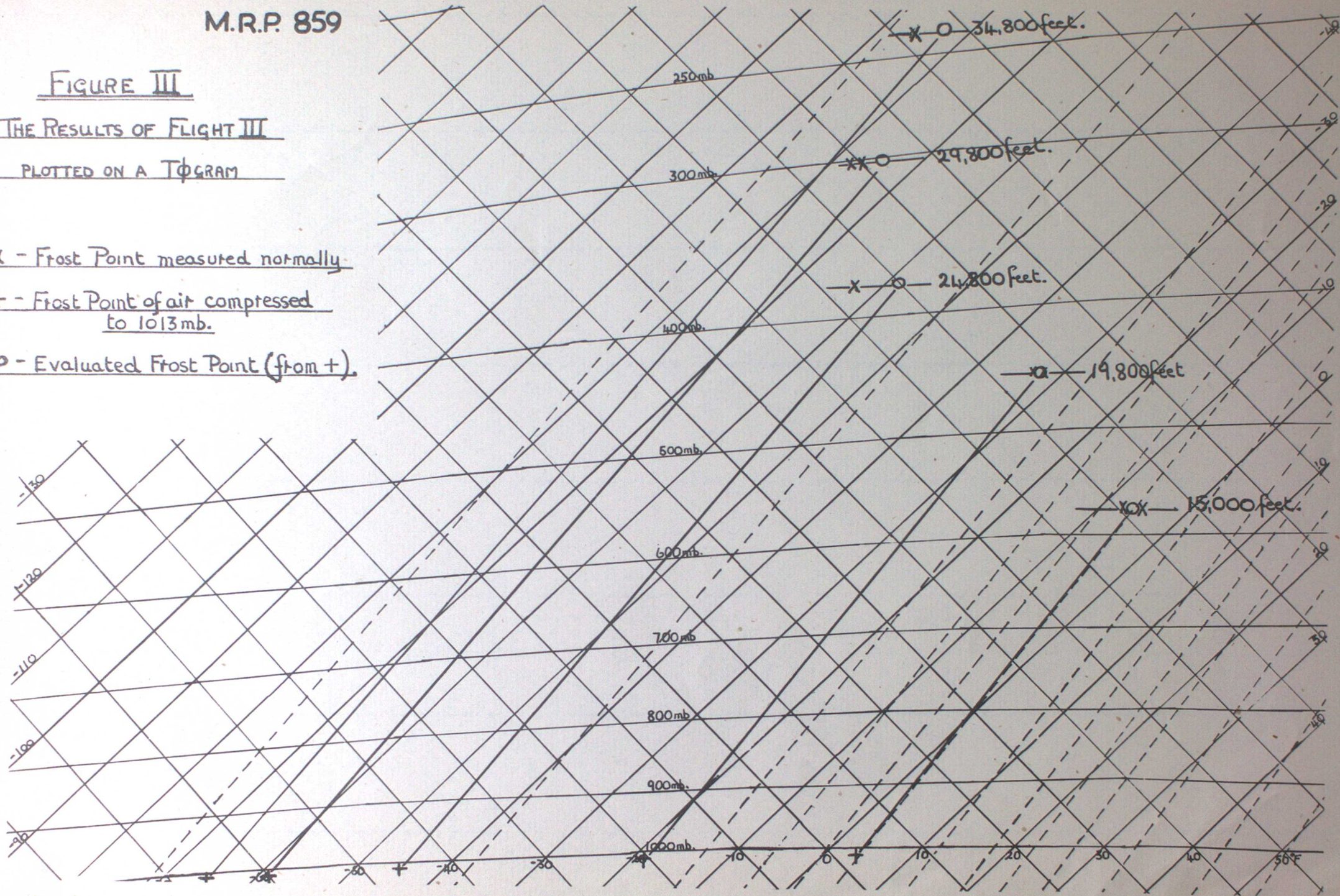
THE RESULTS OF FLIGHT III

PLOTTED ON A TΦGRAM

X - Frost Point measured normally.

\+ - Frost Point of air compressed to 1013 mb.

o - Evaluated Frost Point (from +).



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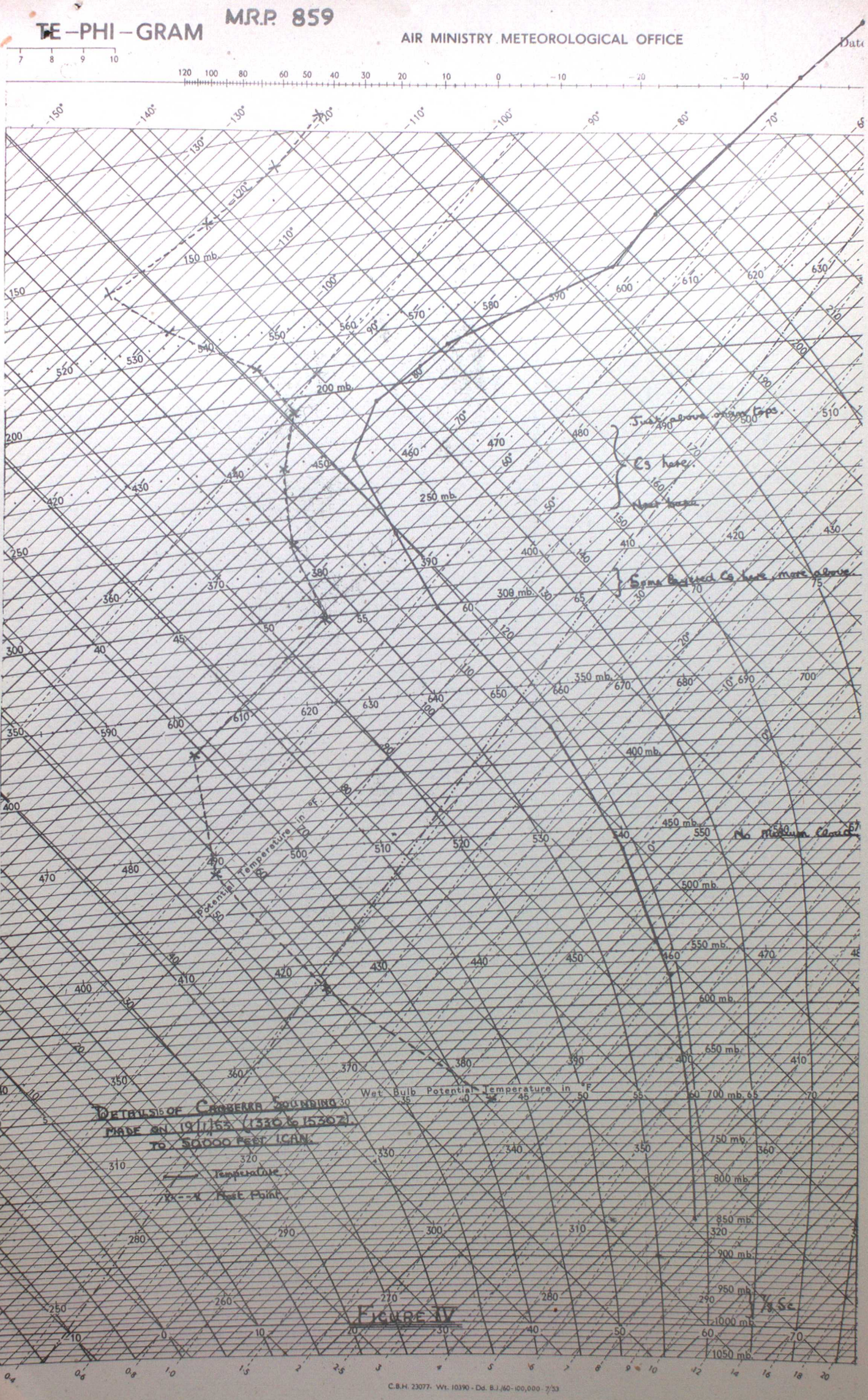

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